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System for Wheezing Detection in Lung Sounds

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Abstract: A lung disease is mainly characterized by the variations that occur in breathing sound of human being. These variations are characterized as wheezes, crackles, etc. Wheezes are one of the most important adventitious sounds in pulmonary system. They are observed in asthma, chronic obstructive pulmonary disease (COPD) and bronchitis. The current method of detecting a lung disease for example asthma involves usage of spirometers and stethoscope. Spirometry proves to be difficult for patients with heart problems and children as it involves blowing air thrice in the spirometer. The results with stethoscope are not efficient. A wheezing detection system may help physicians to monitor patients over the long-term. This technique involves converting the recorded sound into image by applying short time Fourier transform. The image needs to be analyzed. The analysis involves extracting features that define the occurrence of wheezes. Image being in the raw form needs to be processed. The image processing involves noise removal. The preserved image components are then studied and classified based on their occurrence (frequency, total time, amplitude etc).

Keywords: Wheeze; Spectrogram; Image processing; Thresholding; MATLAB; Pattern recognition; Support Vector Machine (SVM).

I. Introduction

A person when breathes a particular pattern is generated. When there are variations in breathing due to some sort of disease the pattern produced is different. Sounds generated from breathing can be a good source of information on lungs health. Abnormal lung sounds may be classified according to two main categories: crackles and wheezes. Wheeze sounds are characterized by a dominant frequency, usually over 100 Hz, and duration of more than 100ms [2]. Their presence is related to partial airway obstruction. Therefore, its auscultation has been used for the detection and evaluation of diseases such as asthma. In contrast, crackles are short, explosive and discontinuous sounds, shorter than 100ms, usually occurring during inspiration. These adventitious sounds are classified as fine crackles and coarse crackles based on their duration. Thus, fine crackles are defined as those lasting less than 10ms and coarse crackles are defined as those lasting more than 10ms. Current methods of diagnosing asthma include auscultation, spirometers, and determining peak expiratory flow to ascertain pulmonary conditions [3]. Conventional stethoscope auscultation is safe and convenient, but also extremely subjective, and cannot be generalized; thus, using auscultation to recognize wheezing is dependent on how experienced the practicing physician is. Although spirometers are used to measure lungs, spirometers induce patient discomfort and are inappropriate for long-term monitoring [1]. In contrast to traditional manual wheezing detection methods, the use of recording devices to collect and analyze lung sounds has been extensively studied in recent years.

The identification of abnormal lung sound characteristics using signal processing methods could help physicians to identify physiological mechanisms generated by lung sounds and their associated pathological link. Because these signal processing methods are objective, their use may also help to establish a classification system to accurately quantify normal and abnormal breath sounds [2]. However, lung sounds have naturally non-stationary signals. This property can be observed both in healthy normal and abnormal subjects. But this non-stationary is more severe in cases of abnormal lung sounds. Therefore, significant diagnostic information can be obtained from the frequency distribution of lung sounds, with the selection of the signal processing technique used to extract this information being very important to maximize the efficiency of extraction [4]. This task has motivated many studies on the classification of lung sounds using frequency analysis.

The spectrograms are usually restricted to the visualization of the spectral information of lung sounds. Since wheezes are musical or continuous abnormalities, their presence demonstrates a typical picture in the spectrogram [7]. In this image, a wheeze shows continuous horizontal lines, representing the time interval of the main frequency, and the presence of other horizontal lines representing the frequency spectra that compose the wheeze, being usually harmonic frequencies of the main frequency.

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Our project based on lung disease detection also makes use of this concept. Audio of a breathing sound is converted into an image by the application of STFT. The graph of time vs frequency is thus generated and it is known as Spectrogram. This acts as input to the system. The features of the episodes of breathing are then extracted. The further process is classification of normal breath, crackling or wheezing sound based on these features. Features like the time duration of wheezing episode, frequency, location prove useful in classification. For classification a support vector machine is designed. The features act as the input to SVM.

II. Material and Methods

A. Wheezing Detection Algorithm Process Flow

The flow chart shows the entire flow of project. Recording of breathing sound is achieved using micro-controller hardware. The Hex values collected from hardware is then converted into .wav file and then the data is ready to process further. On this .wav file image processing Algorithms are applied. By applying STFT, the sound file is converted into an image. On this Spectrogram bilateral filtering and area thresholding is applied. Features are extracted from this image. Classifier classifies given input
in two classes;
Wheezing and normal, and result is displayed on Graphical user interface.

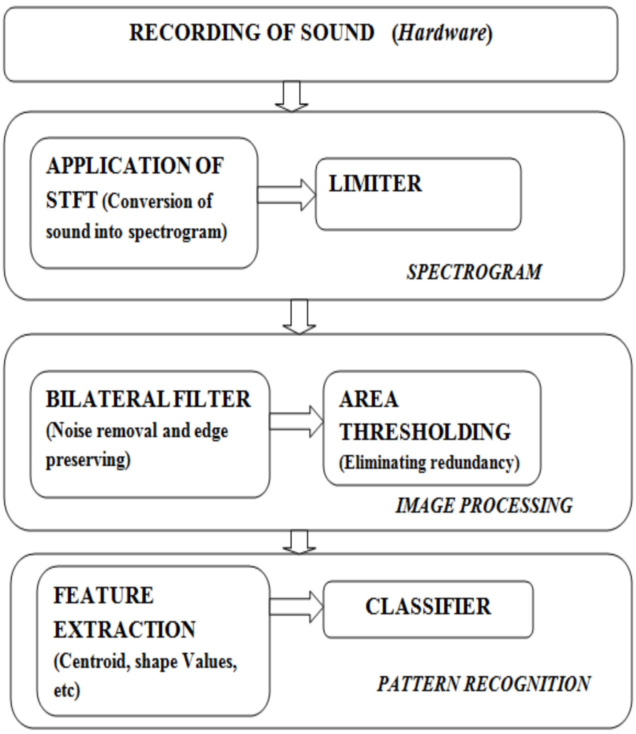
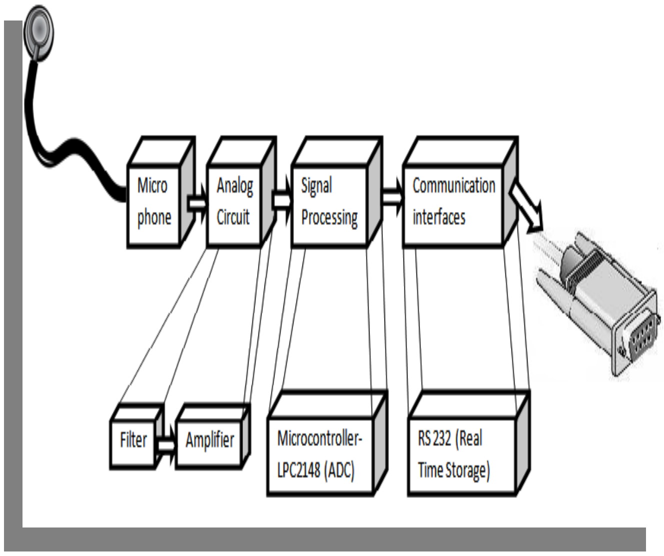


Figure 1: Flow of Project



B. Hardware Architecture

The collection of breathing sounds is another critical part of the system. A microcontroller based circuit has been designed to collect the sound. A stethoscope with mic forms the sensor part. The output of which is filtered, amplified and transferred to microcontroller. The microcontroller converts the signal into digital format and transfers it to computer

Figure 2: Block Diagram of Hardware

through RS232 interface. The hex values are then collected and .wav file is formed, onto which STFT is applied in MATLAB.

C. Spectrogram generation and limiter

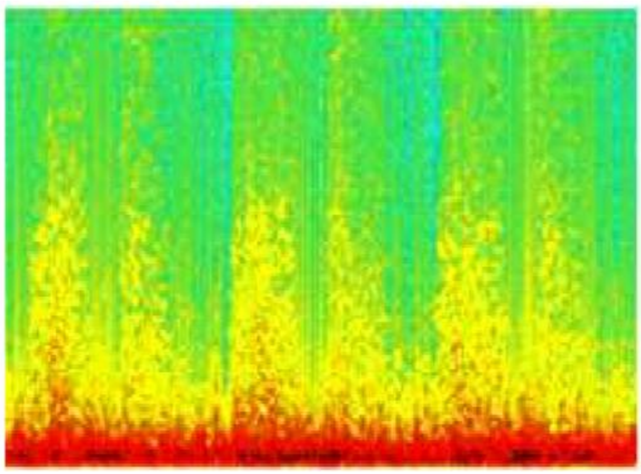


Figure 3: Spectrogram of the normal sound

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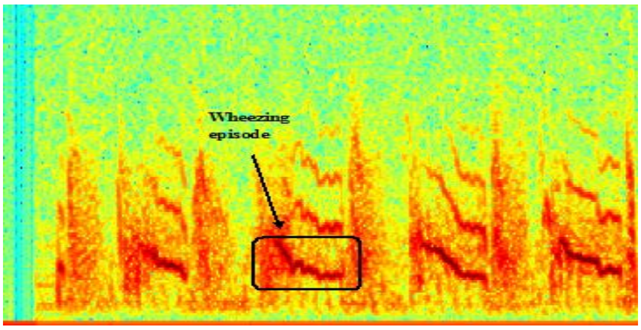

Figure 4: Spectrogram of the wheezing sound

Initially, respiratory sound file is loaded in MATLAB and some parameters regarding the length of the discrete Fourier transform, the type and length of time window, and overlapping percentage are defined. We use a short time Fourier transform with a length of 1920 points to achieve an adequate frequency resolution of 16 KHz/pixel. The Hamming window is used to obtain a rather smooth and acceptable spectrum. The overlap of window is greater than 75 percent. Obtained spectrogram is as shown in Fig.4

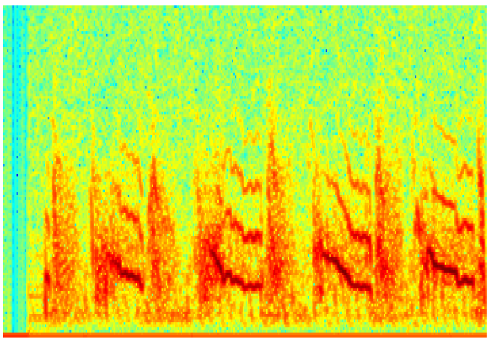

Figure 5: Spectrogram after limiting

In order to isolate the high amplitude components, a limiter is developed. As different sounds can be recorded with different techniques, the resultant signal can present a variable recording level. To obtain the same limitation to any record level. After passing through the limiter, the wheeze episodes of spectrogram are more easily observed than in the original spectrogram.

D. Image Processing

i. Bilateral filter

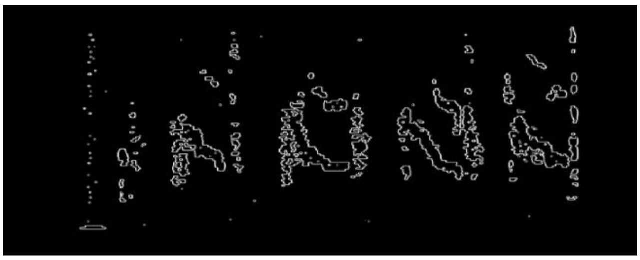

Figure 6: Output of Bilateral Filter

The bilateral filter is a non-linear technique that can blur an image while respecting the strong edges. The bilateral filter is also defined as a weighted average of nearby pixels, in a manner very similar to Gaussian convolution [3]. The difference is that the bilateral filter takes into account the difference in values with neighbors to preserve edges while smoothing. The key idea of bilateral filter is that for a pixl to influence another pixel, it should not only occupy a nearby location but also have a similar value. Its formulation is simple: each pixel is replaced by a weighted average of its neighbors [4]. It depends only on two parameters that indicate size and contrast of the features to preserve. It can be used in non-iterative manner. It can be used at interactive speed even on large images.

$$BF[I]p = \frac{1}{Wp}\sum_{q \in s} G\sigma s(\|p-q\|)\, G\sigma r(|Ip-Iq|)Iq$$

$$Wp = \sum_{q \in s} G\sigma s\,(\|p-q\|) G\sigma r(|Ip-Iq|)Iq$$

The bilateral filter smoothens an input image while preserving its edges. Each pixel is replaced by a weighted average of its neighbors. Each neighbor is weighted by a spatial component that penalizes distant pixels and range component that penalizes pixels with a different intensity [3]. The combination of both components ensures that only nearby similar pixels contribute to the final result.

ii. Area Thresholding

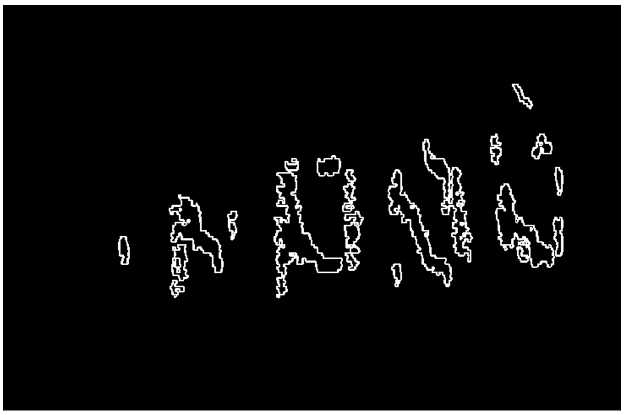

Figure 7: Shapes after Area Thresholding

In medical applications, datasets usually contain high dimensional feature spaces with relatively few samples that lead to poor classifier performance. To overcome this problem, eliminating redundant features provides better accuracy and computational time. A threshold is decided based on studying the images for two or three samples. The

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area is basically a scalar value which is nothing but the number of pixels enclosed by the shape.

E. Pattern recognition

i. Feature extraction

The next step after area thresholding is extraction of features. The features that define the position, shape, etc. are chosen. These are centroid, shape value and frequencies with dominant power. The detailed explanation is as follows:

a. Centroid and Shape value

Centroid value: Centroid of a two-dimensional region is

Figure 8: Centroid an arbitrary shape

an arithmetic mean (”average”) position of all the points in the shape. It specifies the center of mass of region. To measure the proximity of the centroids with each other variance of its x and y co-ordinates is calculated.

Variance is always non-negative: a small variance indicates that the data points tend to be very close to the mean (expected value) and hence to each other, while a high variance indicates that the data points are very spread out around the mean and from each other.

$$Shape\ Value = \frac{4 * \pi * Area}{Perimeter^2}$$

Shape value: Shape factor is dimensionless quantity that numerically describes the shape of a particle, independent of its size. Arithmetic mean of such shapes is calculated, which acts as the input to the classifier.

b. Frequencies with dominant power

For detection of wheezing this can also be an important parameter. We calculated first three dominant power frequencies. However this is not obtained from a processed spectrogram. However the output parameters of spectrogram are used in the process.

ii. Plotting of Features

As it can be seen in the above three figures, the features extracted from spectrogram are separable. An optimum classifier needs to be selected. The detailed explanation of classifier is given in the next section

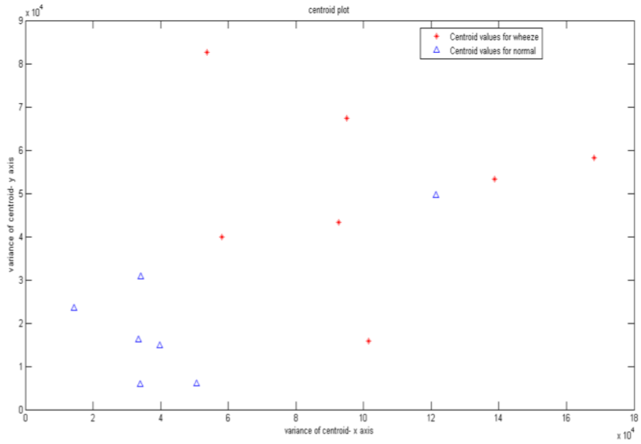

Figure 9: Plot of centroid value

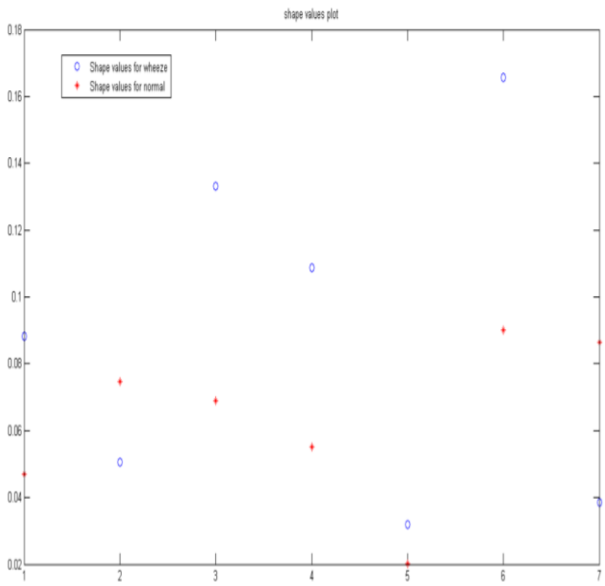

Figure 10: Plot of shape values

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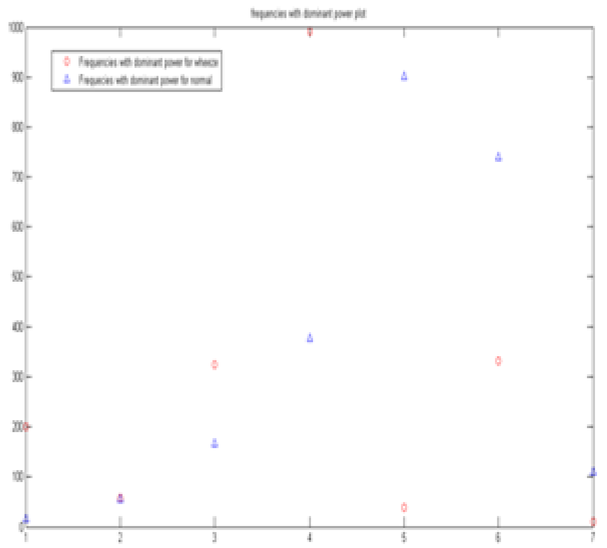

Figure 11: Plot of frequencies with dominant power

iii. Classifier: SVM

Artificial Neural Network (ANN), a brain-style computational model, has been used for many applications. Researchers have developed various ANN's structure in accordant with their problem. After the network is trained, it can be used for image classification.

Support Vector Machine (SVM) is primarily a classifier method that performs classification tasks by constructing hyper planes in a multidimensional space that separates cases of different class labels. Support vector machines are supervised learning models with associated learning algorithms that analyze data and recognize patterns, used for classification and regression analysis. Given a set of training examples, each marked as belonging to one of two categories, an SVM training algorithm builds a model that assigns new examples into one category or the other, making it a non- probabilistic binary linear classifier. An SVM model is a representation of the examples as points in space, mapped so that the examples of the separate categories are divided by a clear gap that is as wide as possible. New examples are then mapped into that same space and predicted to belong to a category based on which side of the gap they fall on.

The advantages of support vector machines are:

- Effective in high dimensional spaces.
- Still effective in cases where number of dimensions is greater than the number of samples.
- Uses a subset of training points in the decision function (called support vectors), so it is also memory efficient.
- Versatile: different kernel functions can be specified for the decision function. Common kernels are provided, but it is also possible to specify custom kernels.

SVM can be classified in two categories:
Linear classifier and Non Linear Classifier

1. Linear Classifier:

For a linearly separable data, the equation for the hyper plane separating classes is given

$$w.x + b = 0$$

2. Non Linear Classifier:

SVM classifier can only have a linear hyper-plane as its decision surface. This formulation can be further extended to build a nonlinear SVM. The motivation for this extension is that a SVM with nonlinear decision surface can classify nonlinearly separable data. The resulting algorithm is formally similar, except that every dot product is replaced by a nonlinear kernel function. This allows the algorithm to fit the maximum-margin hyper plane in a transformed feature space. The transformation may be nonlinear and the transformed space high dimensional; thus though the classifier is a hyper plane in the high-dimensional feature space, it may be nonlinear in the original input space.

As it can be seen in the figs 9, 10 and 11, the feature vectors extracted in our case are separable. But they are separable in a non-linear way. Hence we have used SVM as a non-linear classifier. The kernel which is used to implement SVM is quadratic as it gives the best result for our data.

We also considered Artificial Neural Network (ANN) for the purpose of classification. Perceptron algorithm took less time for classification but the accuracy for our data is very less. Another type of ANN which comes under self-organizing networks i.e., LVQ (Learning Vector Quantization) is also studied and implemented on the data. It is basically a two stage process- a SOM followed by LVQ. It takes more time for classification and accuracy is also not up to the mark.

Thus it can be said that for two class classification problem of ours, SVM classifier gives the best result.

F. Graphical User Interface

Graphical User Interface (GUI) provides point and click control of software applications eliminating the need to learn a language or type commands in order to run the application. Hence a person not aware with the technical details of the code like doctor can use it easily. The GUI typically contains controls such as menus, toolbars, buttons and sliders. A graphical user interface (GUI) is a pictorial interface to a program. A good GUI can make programs easier to use by providing them with a consistent appearance and with intuitive controls like pushbuttons, list boxes, sliders, menus, and so forth.

III. Result and Analysis

The breathing sound is recorded with the help of microphone. The acoustic transducer transforms incoming sound signal into voltage signal which is further amplified and given to ARM processor for recording purpose. The spectrogram of recorded sound is generated and it is then passed through pre-processing, filtering and feature extraction and classification. Features are extracted from spectrogram image. These features act as input to the classifier (Support Vector Machine).Also compared to Spirometry this method is not difficult for patients. The system is user friendly as no expert is needed to handle this.

The real time sound is serially received in MATLAB and result is displayed on Graphic User Interface, whether wheezing is present or not. The accuracy of system achieved will be calculated. The total time required for data collection, Feature extraction and classification in MATLAB is observed. The system is independent of physical parameters of human like age, physical ability, etc.

IV.Future Scope

The system can be further improved for classifying crackles from normal breathing and wheezing. Also by collecting more real world data with the help of the mentioned hardware and adding into the training samples will make the system more efficient. Early detection of crackles and wheezing can be achieved using this technique. The hardware can be further improved for removal of noise by making the amplifier more efficient.

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